# MISSOURI RIVER DESIGN STUDY

## MRD HYDRAULIC LABORATORY SERIES
## REPORT NO. 1

# OPERATION AND FUNCTION OF THE MEAD HYDRAULIC LABORATORY

MEAD, NEBRASKA

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U. S. ARMY ENGINEER DISTRICT, OMAHA
U. S. ARMY ENGINEER DISTRICT, KANSAS CITY
MISSOURI RIVER DIVISION, OMAHA
MARCH 1969

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The Mead Hydraulic Laboratory is located at the University of NE Field Laboratory near Mead, NE. It is operated as a joint use project under a special lease arrangement between the University and the Missouri River Division of the Corps of Engineers. The primary facility consists of a model area and related equipment utilized by the Corps of engineers for investigations of structures for the development and maintenance of the navigable channel of the Missouri River.

This facility was designed specifically to permit rapid evaluation of improvements and expedients suggested to develop ~~and~~ the constructed channel to optimum efficiency.

New ideas can first be tested in the laboratory, thereby giving the design engineer some advance insight into the adaptability of the idea in the prototype.

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DEPARTMENT OF THE ARMY
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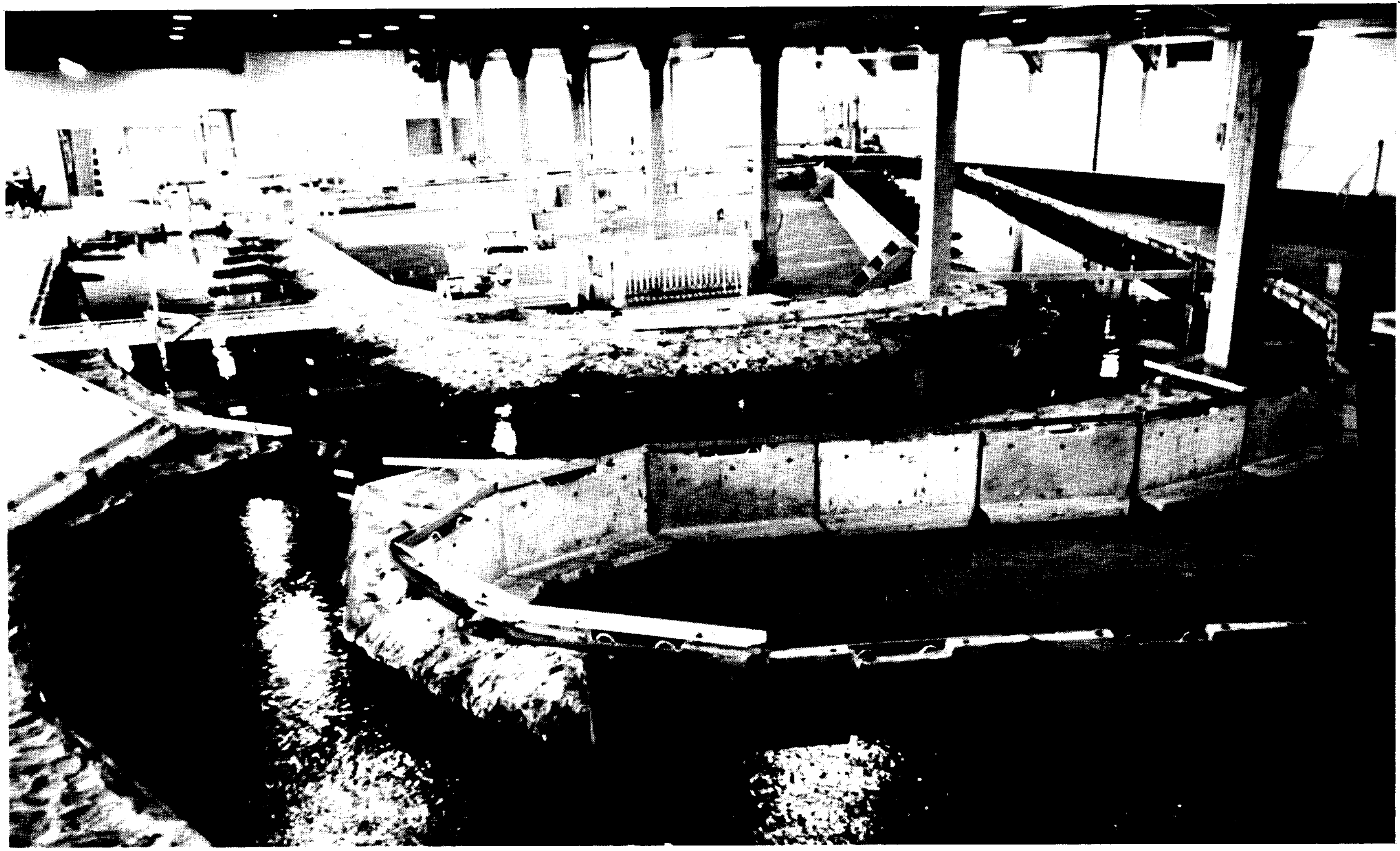
# OPERATION AND FUNCTION
# OF THE
# MEAD HYDRAULIC LABORATORY
# MEAD, NEBRASKA

U. S. ARMY ENGINEER DISTRICT, OMAHA, NEBRASKA
U. S. ARMY ENGINEER DISTRICT, KANSAS CITY, MISSOURI
MISSOURI RIVER DIVISION, OMAHA, NEBRASKA

MARCH 1969



General view of the interior of the Mead Hydraulic Laboratory. The model in operation shown in the photo is a study of the navigation channel at the junction of the Kansas and Missouri Rivers near Kansas City, Missouri.

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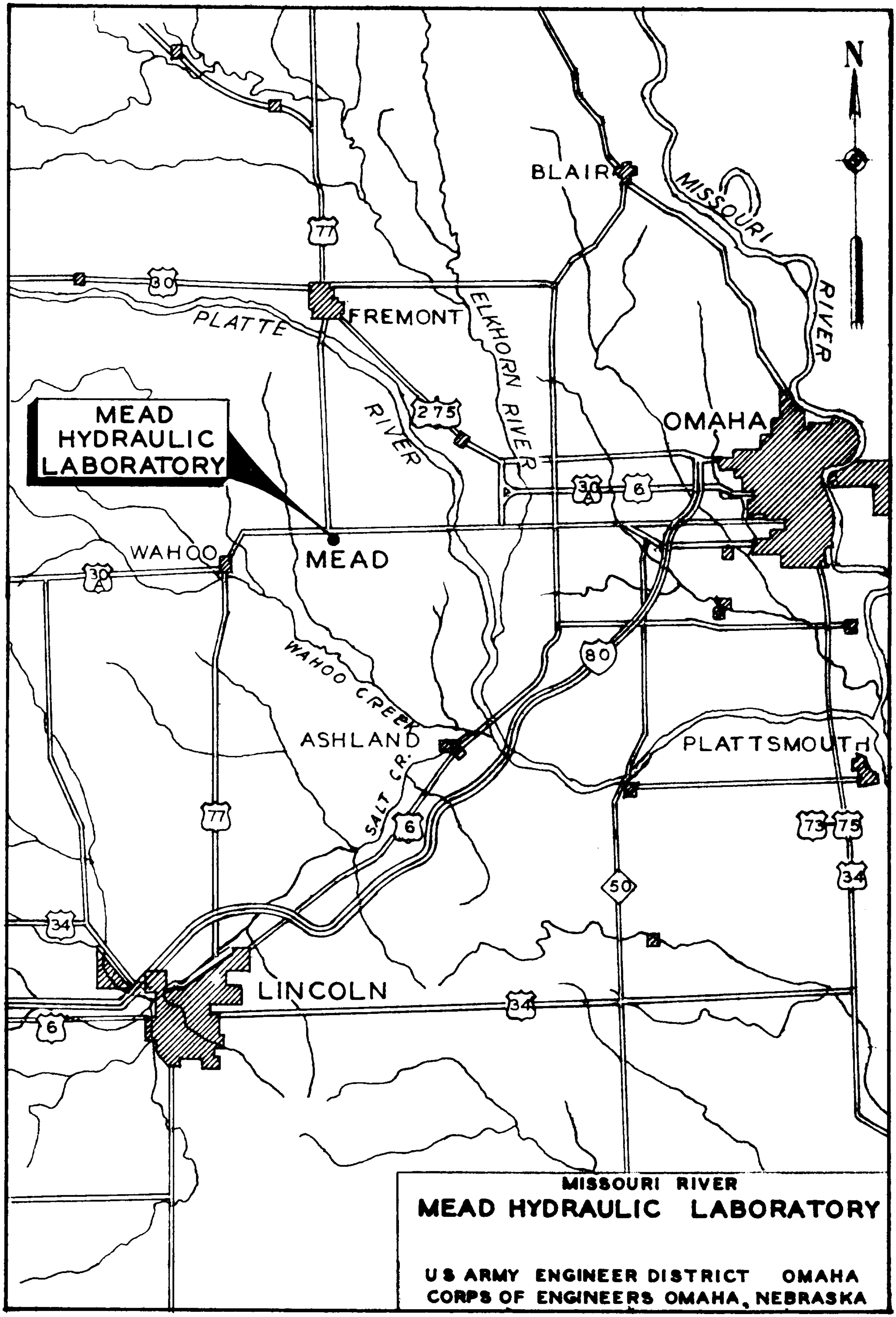

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MEAD HYDRAULIC LABORATORY
US ARMY ENGINEER DISTRICT OMAHA
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Plate I

## INTRODUCTION

1. The Mead Hydraulic Laboratory is located at the University of Nebraska Field Laboratory near Mead, Nebraska (Plate I). It is operated as a joint use project under a special lease arrangement between the University and the Missouri River Division of the Corps of Engineers. The primary facility consists of a model area and related equipment utilized by the Corps of Engineers for investigations of structures for the development and maintenance of the navigable channel of the Missouri River.

2. This facility was designed specifically to permit rapid evaluation of improvements and expedients suggested to develop the constructed channel to optimum efficiency. Typical investigations may be as follows:

a. Methods of improving and stabilizing the navigation channel through river crossings.

b. Studies which would assist in defining the most effective location of training structures in long flat bends of the river.

c. Methods of improving the navigation channel in very sharp bends, where the channel is usually very narrow and deep.

d. Investigations which would establish the most desirable bend curvature for given discharges.

e. Studies on the effectiveness of new types of channel control structures.

f. To simulate the effects of dredging operations on the navigation channel.

g. To establish more efficient construction techniques for rock structures.

h. To study the effects of high discharges on the navigation channel and structures.

i. To observe the effects of skewed bridge piers on the flow distribution and scour patterns.

3. The facility is not limited to studies of the above subjects, but can also be adapted to a wide range of river problems. As interest in water transportation increases, new thoughts and concepts will evolve. These new ideas can first be tested in the laboratory, thereby giving the design engineer some advance insight into the adaptability of the idea in the prototype. Thus, the laboratory serves as an "engineering tool" to both the design and construction engineer.

## THE MODEL BASIN

4. The basin is inclosed in a building 100 feet wide and 160 feet long. The only interior obstructions in the building are two rows of columns which support the roof structure. Portable interior wall sections are used to form the interior boundaries of the particular model under investigation. These sections are inverted T-shaped lengths of pre-cast concrete, four feet long and two feet in height. The sections are equipped with necessary mountings used to attach railings and auxillary measuring equipment to the top or sides of the walls. Figure 1 shows a typical wall section.

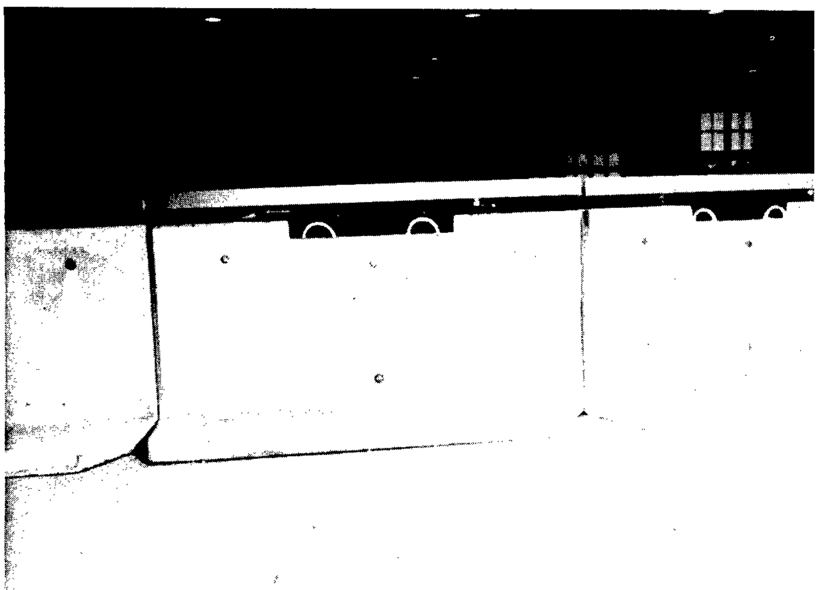


Figure 1. The above photo. shows a typical concrete "T" section used to form the outer basin walls of the flume. These portable sections are sealed together and to the floor to form a watertight basin of any desired size and shape.

5. The portable wall sections allow a large degree of flexibility in laying out various shapes of model basins. Once the proper alignment has been established, the sections are sealed to each other and to the floor with waterproofing compound. At the completion of the study, they are taken apart, and reused for the next model investigation. This method of construction permits rapid changes from one model layout to the next, thus cutting down considerably on the time between model studies.

6. The laboratory has two complete water supply systems, thus permitting two general investigations to be carried out simultaneously. Both systems are equipped with variable speed controls,

and the discharge rate is controlled by adjusting the pump motor speed and through the position of a gate valve in the discharge line. Figure 2 shows a view of the pump assemblies.

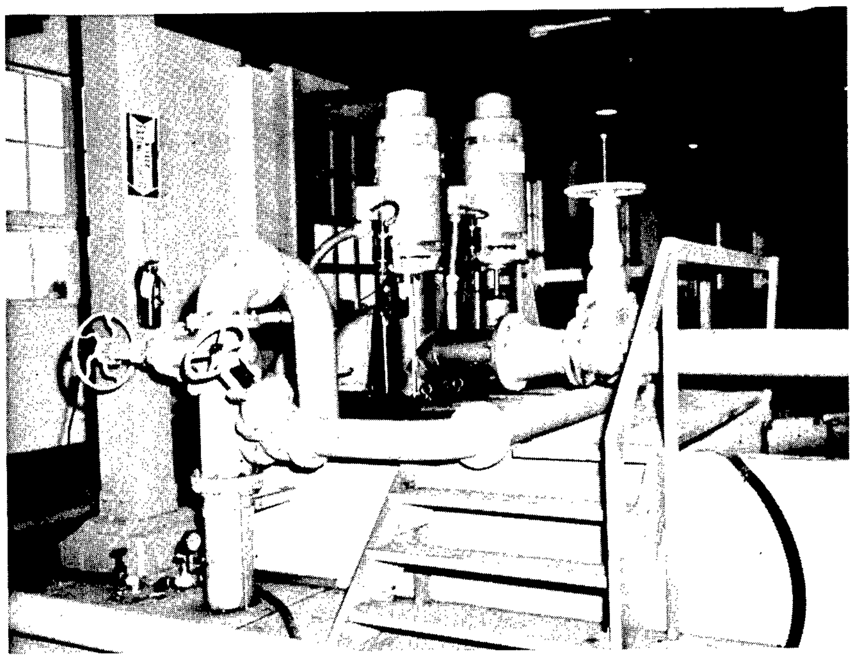


Figure 2. Two pumps, equipped with 15 and 20 H.P. motors recirculate the water and sediment through the system.

7. The water in the model is recirculated by a piping system connecting the basin and a return sump. The sediment in the model can either be recirculated with the water, or be fed into the model at the upstream end at some pre-determined rate. If it is desired to recirculate the sediment, the dimensions of the collection sump are reduced to a minimum, thereby eliminating regions where the material would tend to settle out. No positive control of the sediment transport rate is obtained under these conditions, with the rate being established by the relationship between the hydraulic characteristics present in the model at a given time. This method of operation has been used almost exclusively in the studies performed to date, and has proved satisfactory for investigations involving problems associated with the bed configuration of alluvial channels.

## SIMILARITY CRITERIA

8. The selection of scales for an undistorted fixed boundary model involving only the study of flow characteristics is usually a simple, forthright procedure. The major constraints are the area available, the minimum depth of flow required in the model, and sufficient capacity for supplying fluid to the model. Distortions may be introduced with almost equal facility, the vertical scale may differ from the horizontal or the slope may be distorted. Dynamic similarity is obtained by maintaining a constant Froude Number between the model and prototype. The only factor normally requiring adjustment by judgment or by trial and error is the roughness of the model boundary.

9. The introduction of a mobile boundary in the model immediately complicates the procedure. If the scale reduction is appreciable, it is impossible to reproduce at model scale the physical and dynamic dimensions of the prototype. It becomes necessary to accept the fact that certain scale ratios must be varied in a manner such that the end result is acceptable. The allowable variations may depend largely on the factors to be studied in the model.

10. Distortions in the scales are usually necessary when modeling a natural alluvial stream. Generally if one attempts to model a wide, shallow watercourse and still retain the principles of true geometric similarity, the resulting model either becomes too large for the laboratory, or the depth of flow and the sediment size have to be considerably decreased. This causes the model surface to act as hydraulically smooth boundaries with viscous forces dominating both the water and sediment behavior. To overcome this problem, it usually becomes necessary to distort the various geometric parameters.

11. If the model is designed to study only the general pattern of bar formations at the confluence of two streams, or even to study the effect of channel changes, generally the variations may be accomplished in the type of material used for the model stream bed, the model discharge, the model slope, and the time scale. The flow velocity in the model must be adequate to transport the model bed material, although not necessarily at the corresponding prototype rate. This is accomplished primarily when selecting the model discharge and slope. The disparity in transport rates is taken into account by varying the time scale. This latter variation is usually a matter of trial and error, reproducing known prototype discharges until the model reproduces the known corresponding prototype channel conditions.

12. A model designed to reproduce almost all of the functions of the channel, including transport rates, involves an extremely complicated design. There are available[1] computation procedures by

which these functions can be approximated, accepting certain functions as controls and varying the other functions to an acceptable degree. It will usually be found that a model designed on the basis of these computations must be re-adjusted by trial and error procedures. It may be found that the vertical dimensions of channel bed forms or of scour patterns will be greatly exaggerated, and this may affect the flow characteristics so that the model must be operated at a vertical scale differing from that initially chosen. In this respect, a model which is adequate for operation at a given constant discharge may require revisions to be adequate if it is desired to reproduce a discharge hydrograph.

13. Several relationships relating roughness and sediment transport can be used as aids in verifying model performance. Einstein[2] and Einstein and Barbarossa[3] separate the total hydraulic radius, $R_t$, into two parts, $R'$ and $R''$ where

$$R' + R'' = R_t$$

The value of $R'$ becomes a measure of the hydraulic roughness caused by the size of the grains that form the bed, and $R''$ becomes a measure of the roughness resulting from the channel bars and other boundary roughness. The following equation for the average velocity in the vertical can be used to determine $R'$

$$V = 5.75 \sqrt{SR'g} \log_{10} \left( 12.25 \frac{R'}{D_{65}} \right)$$

Where $g$ = acceleration of gravity
$S$ = slope
$D_{65}$ = the grain diameter at which 65 percent of the material is finer

Although it may not be possible to reproduce values of $R'$ to scale, a similarity should exist if it is possible to obtain comparable values of the ratio $R'/R_t$ between the model and prototype.

14. A second relationship which may be used to indicate similarity between model and prototype, represents the intensity of shear on the bed and may be determined from:

$$\psi' = \frac{(S_s - S_f) D_{35}}{S_f R' S}$$

in which $\psi'$ = the intensity of shear on a representative particle
$S_s$ = the specific gravity of the bed material
$S_f$ = the specific gravity of the fluid
$D_{35}$ = the grain diameter at which 35 percent by weight is finer
$R'$ and $S$ as previously defined.

15. Einstein[1] indicates that in order for the model and prototype to have similar sediment transport characteristics near the bed it is

generally necessary for the ratio $\psi'_p/\psi'_m$ to equal unity, where p and m refer to the prototype and model, respectively. An examination of the expression for $\psi'$ will immediately show that if the same bed material is used in the model as in the prototype, it will be virtually impossible for the value of $\psi'_p$ to approach $\psi'_m$, as the small value of $R'_m$ will make the value $\psi'_m$ much larger than $\psi'_p$. One way of making the ratio approach unity is to use a lightweight material for the bed material in the model.

16. In the case of sand bed streams which transport a predominate suspended load, it is very difficult to satisfy the many, and often conflicting similitude criteria with the physical limitations imposed by available model space, model discharge capacity, and the availability of model fluids and sediments. The result is that while the rigorous similarity criteria are duly noted and approximated whenever practical, distortions in vertical scale, transport scale, velocity scale, hydraulic resistance and scale are introduced in order to obtain the desired result.[4]

17. The choice of model scales is subject to several practical constraints.[5] The vertical scale must be large enough to permit measurements of channel cross sections, profiles, etc., to be made with enough precision that comparisons of successive measurements will be significant. Consider for example a 1:120 horizontal scale model of a prototype in which the average depth is 10 feet. With no vertical distortion, the water depth in the model would be 10 ÷ 120 = 0.083 feet, which is too shallow for practical purposes. Since 0.15 to 0.20 feet has been found to be the minimum practical model depth using the measuring techniques described herein, the vertical scale must be distorted to at least twice the horizontal scale in order to relieve this constraint.

18. In models where there are several spur dikes or other structures which protrude into the channel to induce local scour, the amount of vertical distortion must be kept to a minimum. The geometry of local scour holes tends to be a function of the water depth and tends to be proportional to the vertical scale rather than the horizontal scale. If the depth distortion is great and there are a number of protruding structures, the distorted local scour patterns may obscure the other channel features.

19. The time scale for bed changes to occur is a practical consideration. The velocity must be high enough and the bed material light-weight enough to produce a transport rate that allows equilibrium conditions to be established and the results of design changes to be observed within a reasonable time. Furthermore, where deposition in such locations as inside boat basins or behind submerged channel structures is a subject for investigation, it is desirable

that some bed material be entrained as suspended load in order to simulate the deposition pattern. The following table illustrates the effect of transport rate on the time scale for bed changes in the Pomeroy Bend model performed at the laboratory.

Pomeroy Bend Model Study

| | Using Sand as Bed Material S.G. = 2.65 | Using Walnut Shells as Bed Material S.G. = 1.30 |
|---|---|---|
| Horizontal scale, h | 1:150 | 1:150 |
| Vertical Scale, v | 1:58 | 1:58 |
| Specific gravity of sediment, s | 1:1 | 1:2.04 |
| *Sediment load, $q_s$ | 1:5,400,000 | 1:95,000 |
| Sediment time, $t_s = \frac{h^2vs}{q_s} =$ | 1:0.25 | 1:27 |

*Estimated by Methods in Reference (1)

Overall changes in channel configuration, other than local scour, are estimated to occur about 100 times faster in the model with light weight bed materials. This gives an important operational advantage.

20. In the present state of the art, the selection of scales for modeling stabilized river reaches is a semi-empirical process in which depth and discharge scales are adjusted until the model appears to reproduce the most important overall channel characteristics in the prototype. This is commonly referred to as the "verification process". Details of the verification process and selection of scales for models of two reaches in the Missouri River are discussed later in this report.

## MEASUREMENT PROCEDURES

21. A continuous record of the total sediment transport rate is obtained while the flume is in operation. A ¼" copper tube is inserted in the supply line and pointed into the flow. A variable speed pump assembly is adjusted to withdraw a continuous sample of water and sediment (walnut shells) at the same velocity as the average velocity in the return line. The water and sediment mixture is pumped into an inverted cone where the sediment is allowed to settle out. The overflow from the cone is drained back into the flume. The material which settles out is collected at equal time increments during a test and weighed immediately. The accumulative and incremental transport rates during a test can then be determined. Part of the material is saved and analyzed for size distribution and specific gravity determinations. The following photos show the sediment system currently in operation.

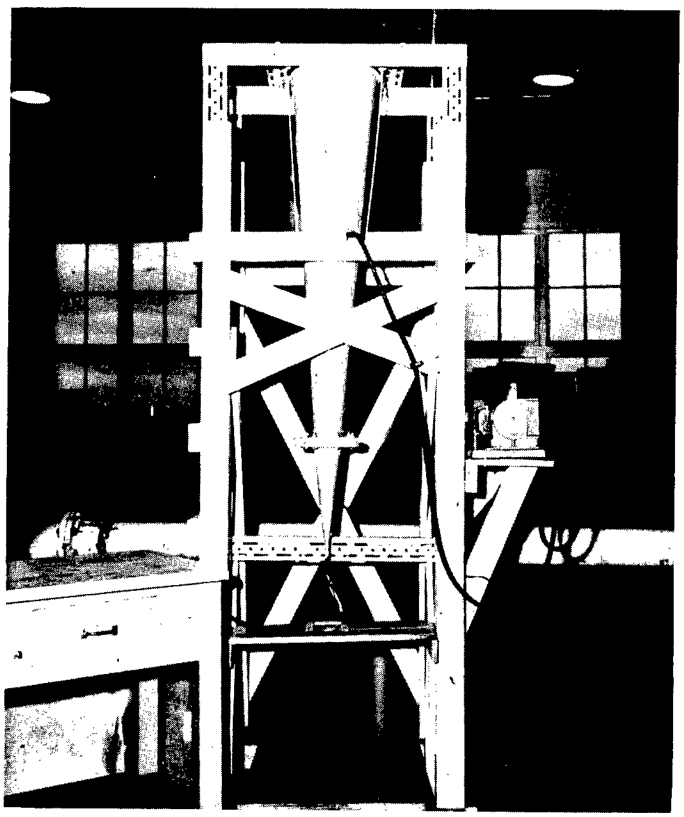
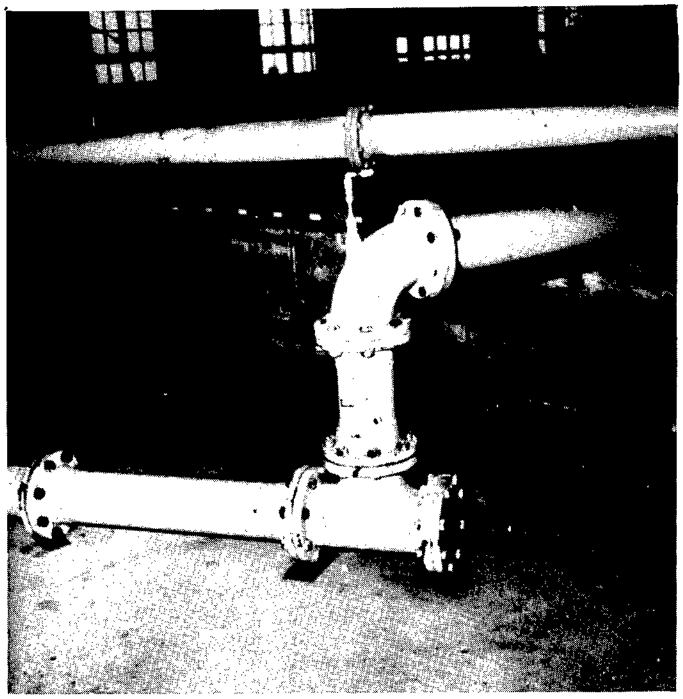
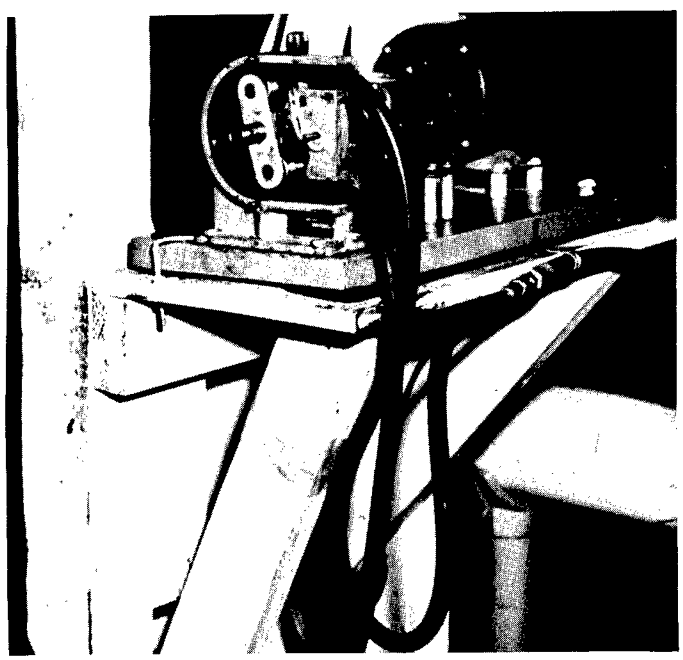


Figure 3. The water and sediment mixture is pumped into an inverted cone where the sediment is removed at regular intervals during a test run. Excess water is removed near the top of the cone and allowed to drain back into the flume.



The sediment sample is removed from the system in a vertical segment of the supply line shown in Figure 4 above. The mixture is pumped from the supply line into a settling cone with the small pump assembly shown in Figure 5 below.



22. The slope of the energy gradient is measured with a series of impact tubes spaced along the model channel. The tubes are connected by plastic hoses, buried in the bed material, to a bank of individual stilling wells in which the water surface elevation representing the energy head in the channel at that location is measured with a point gage. This method of measuring the energy slope directly has proved to be very satisfactory, even though the change in the water surface slope through the model is usually less than 0.2 feet and the velocity less than 0.5 fps. Figures 6 thru 9 show the impact tube stand currently being used in the laboratory.

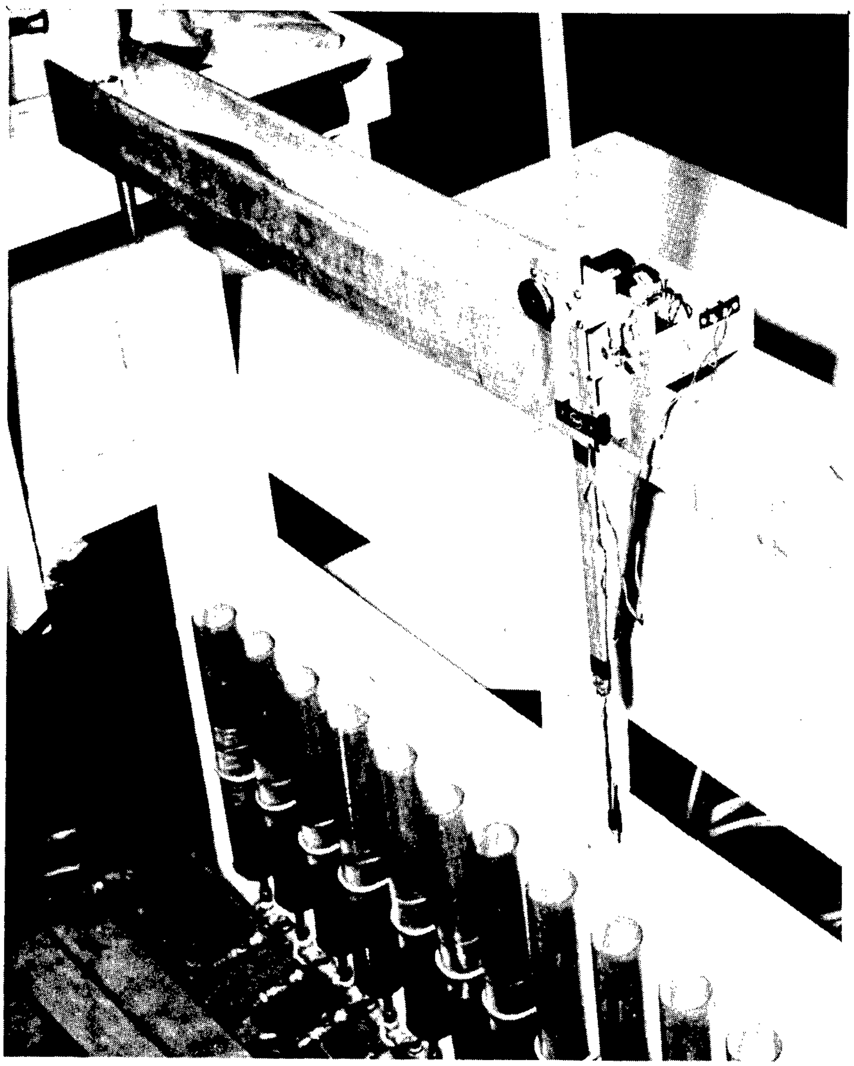
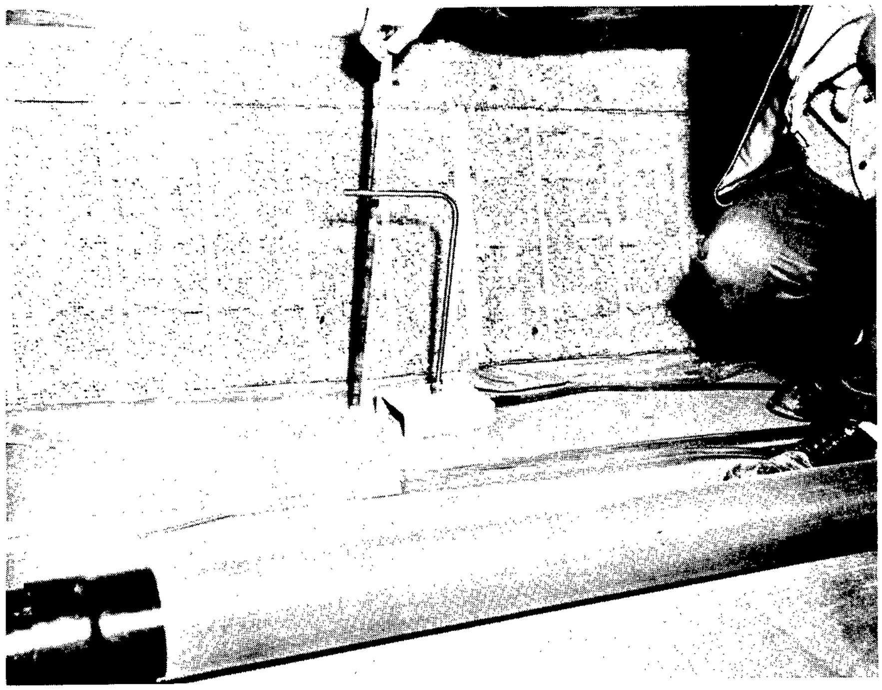
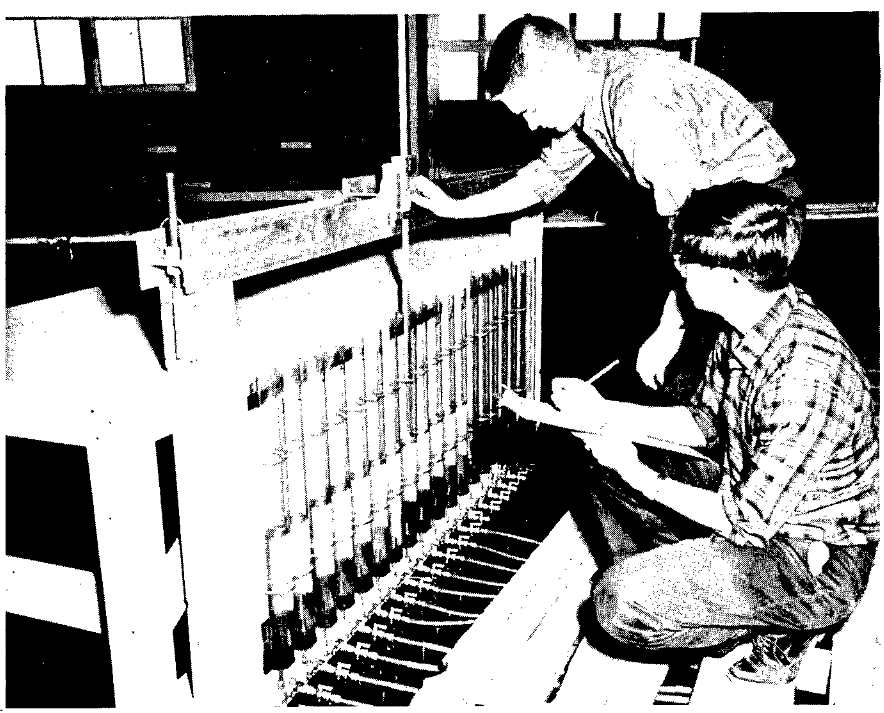


Figure 6. A point gage similar to the one shown above is used to determine the energy gradient through the flume. This unit is equipped to light a small bulb when the tip of the gage comes in contact with the water.



Figures 7 and 8. Impact probes similar to those shown in upper photo are placed at 10 foot intervals throughout the flume and connected by plastic tubes to a central location (lower photo) where the elevations are recorded with a point gage.



23. Cross sections in the model are obtained through the use of an echo-sonic depth sounder. This instrument, called a Dual Channel Stream Monitor is manufactured by Automation Industries, Inc., Boulder, Colorado. It was developed for use in an alluvial channel under dynamic conditions[7]. High frequency water borne sound waves are generated and received by piezoelectric ceramic transducers. The time differential between transmission of sound and reflection of the sound wave or echo is used to indicate distances to specific reflecting surfaces.

24. The transducer is mounted in the end of a three foot probe. The probe is attached to a moveable carriage which is equipped to move across a bridge which spans the width of the model. The carriage containing the probe and transducer is transported across the bridge by means of an endless cable powered by a 1/12 H.P. motor. The location of the carriage is indicated by the voltage output across a potentiometer attached to the gear mechanism driving the cable drum. The DC voltage across the potentiometer is supplied by a Model 6203B Harrison Power Supply.

25. The two output voltages, one from the stream monitor, and the other from the potentiometer serve as the inputs to an X - Y plotter. As the carriage containing the transducer moves across the bridge, a complete cross section of the model is developed by the plotter. The scale of the plotted section is controlled by altering the volts per unit length relationship on the plotter. Cross sections at other locations are made by manually moving the bridge assembly to other locations along the flume. Figures 9 thru 11 illustrate the entire assembly currently being used in the laboratory, and show photographs of the various pieces of equipment.

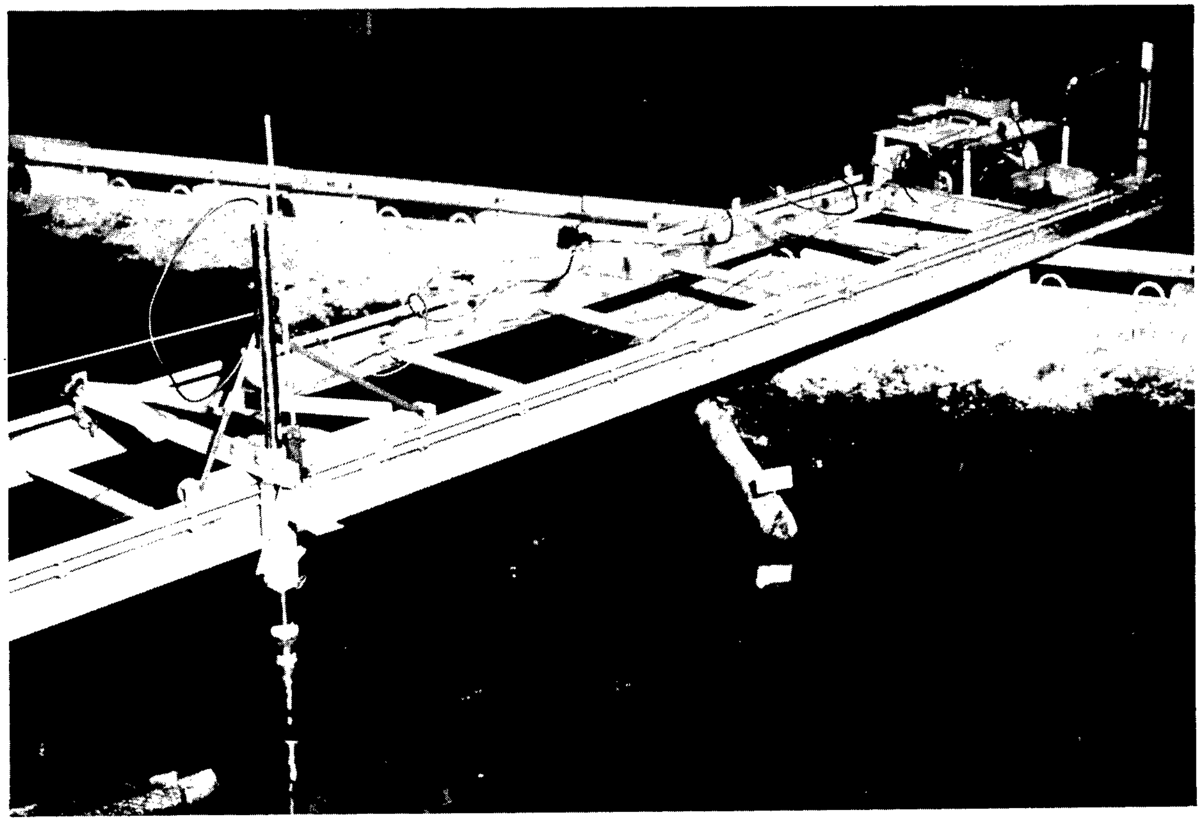
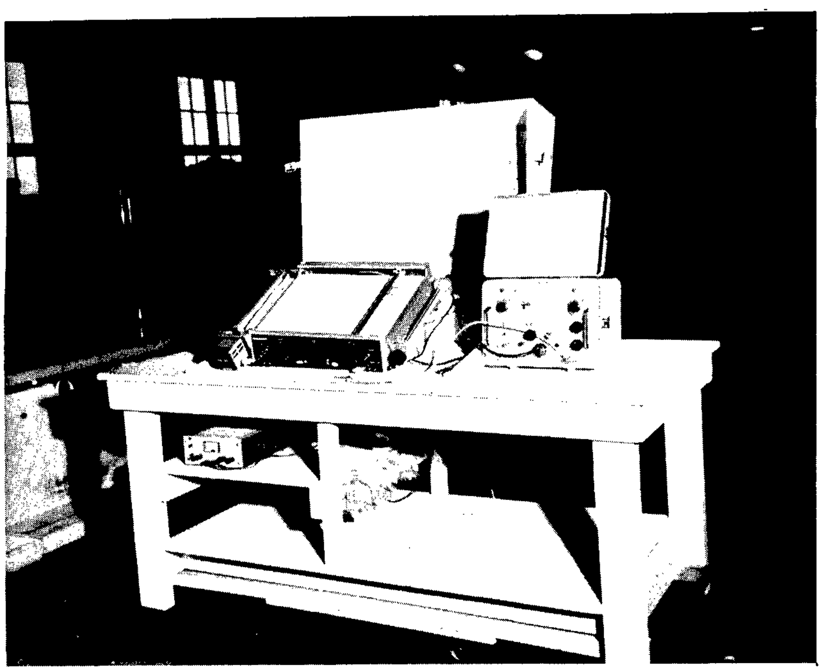
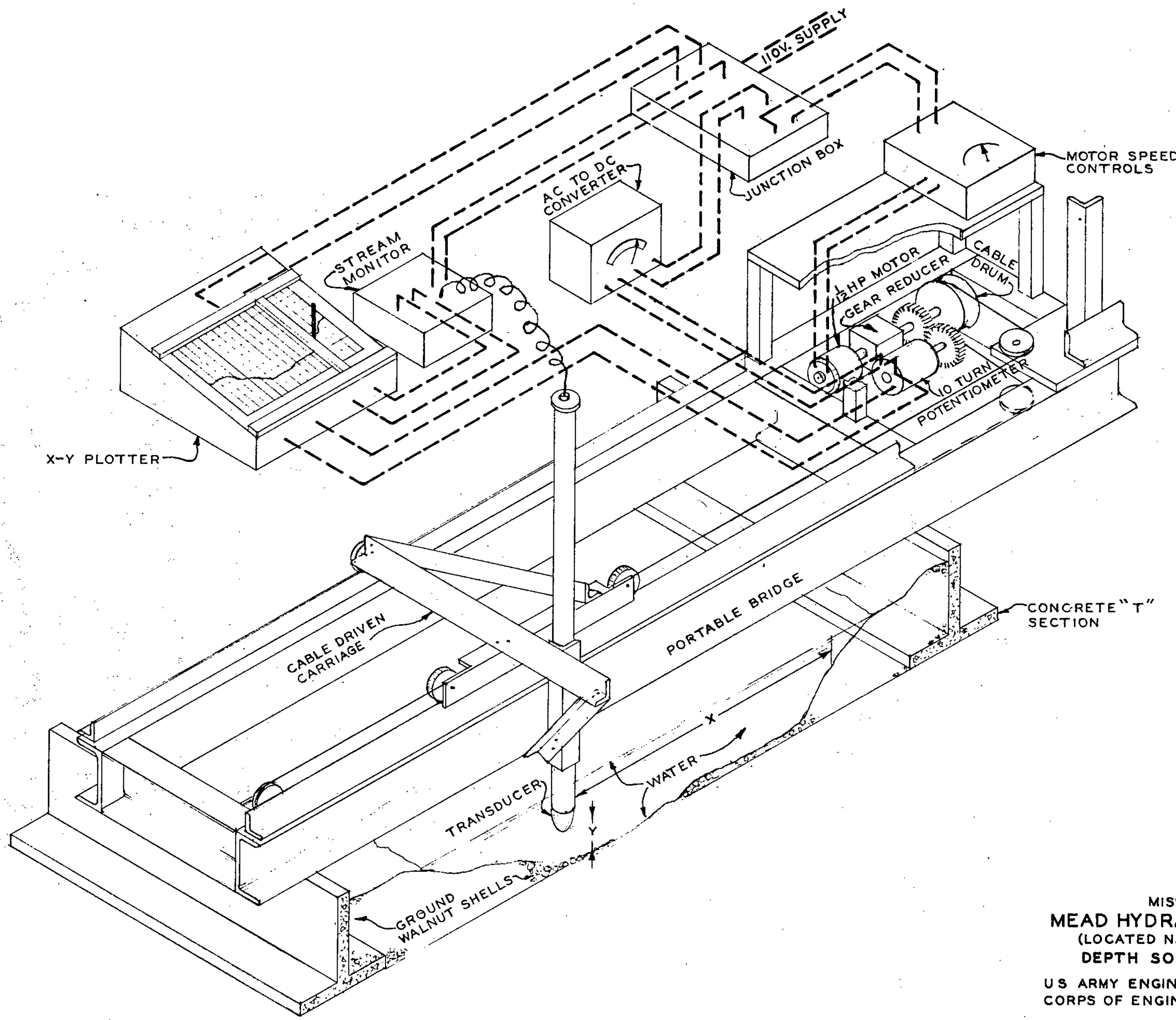


Figure 9 above shows the Depth Sounding Apparatus used to obtain model cross sections. The motorized carriage transports the transducer across the bridge and information is recorded by the X-Y plotter shown in Figure 10 below.



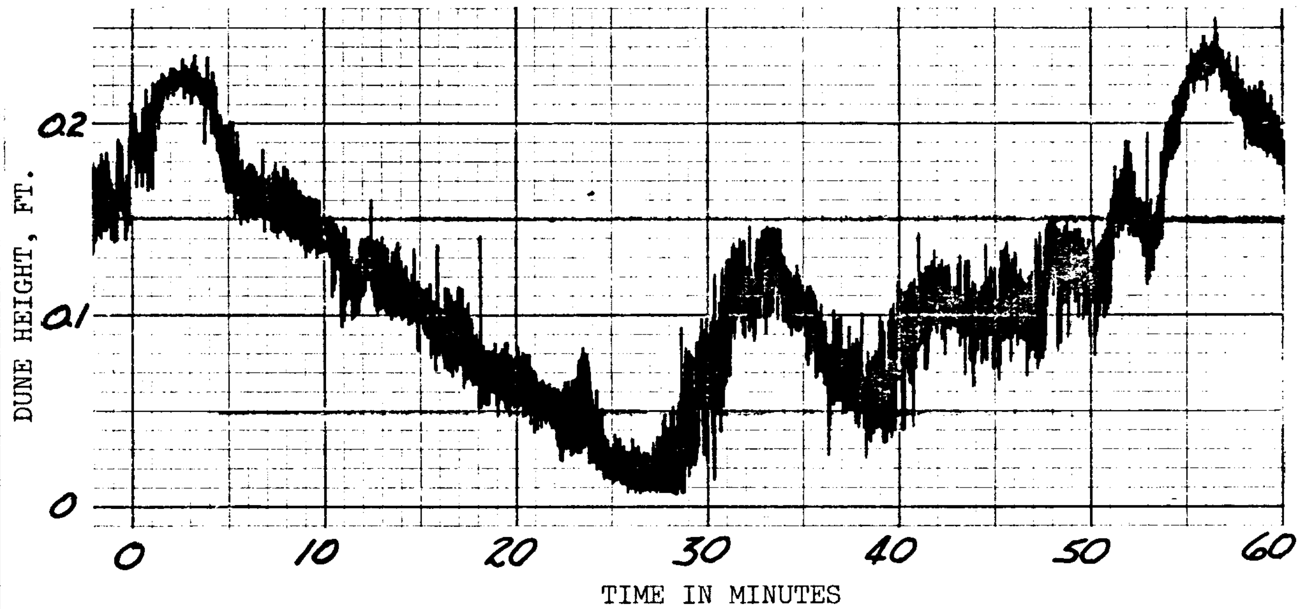



MISSOURI RIVER
MEAD HYDRAULIC LABORATORY
(LOCATED NEAR MEAD, NEBRASKA)
DEPTH SOUNDING APPARATUS

U S ARMY ENGINEER DISTRICT OMAHA
CORPS OF ENGINEERS OMAHA NEBRASKA

26. The movement of dunes past a fixed location can also be observed with the system. When this is being done the plotter is altered to perform like a strip chart recorder, and the transducer held stationary at a point in the flow. The sensitivity of the stream monitor echo is sufficient to send back false signals representing the particles in suspension; however, indications of the true stream bed are visible in the trace. A sample of data obtained in this manner and a view of typical bed forms are shown on Figures 12 and 13. The shape of the formations recorded in this manner are dependent on the speed of the paper on the recorder.

Figure 12. The walnut shells form into ripples and dunes like those shown above and move through the flume as the water passes through the system. Flow was from right to left in the above photo and the horizontal tube in the lower left of photograph is 6 inches long.




The above trace illustrates the movement of the bed forms through the flume. The trace was obtained by making a continuous sounding of the water depth at a fixed location on a strip chart recorder. The wide band shown on the record is caused by the large amount of material in suspension.

Lower trace illustrates a typical model cross section as obtained with a stream monitor and recorded on an X-Y recorder.

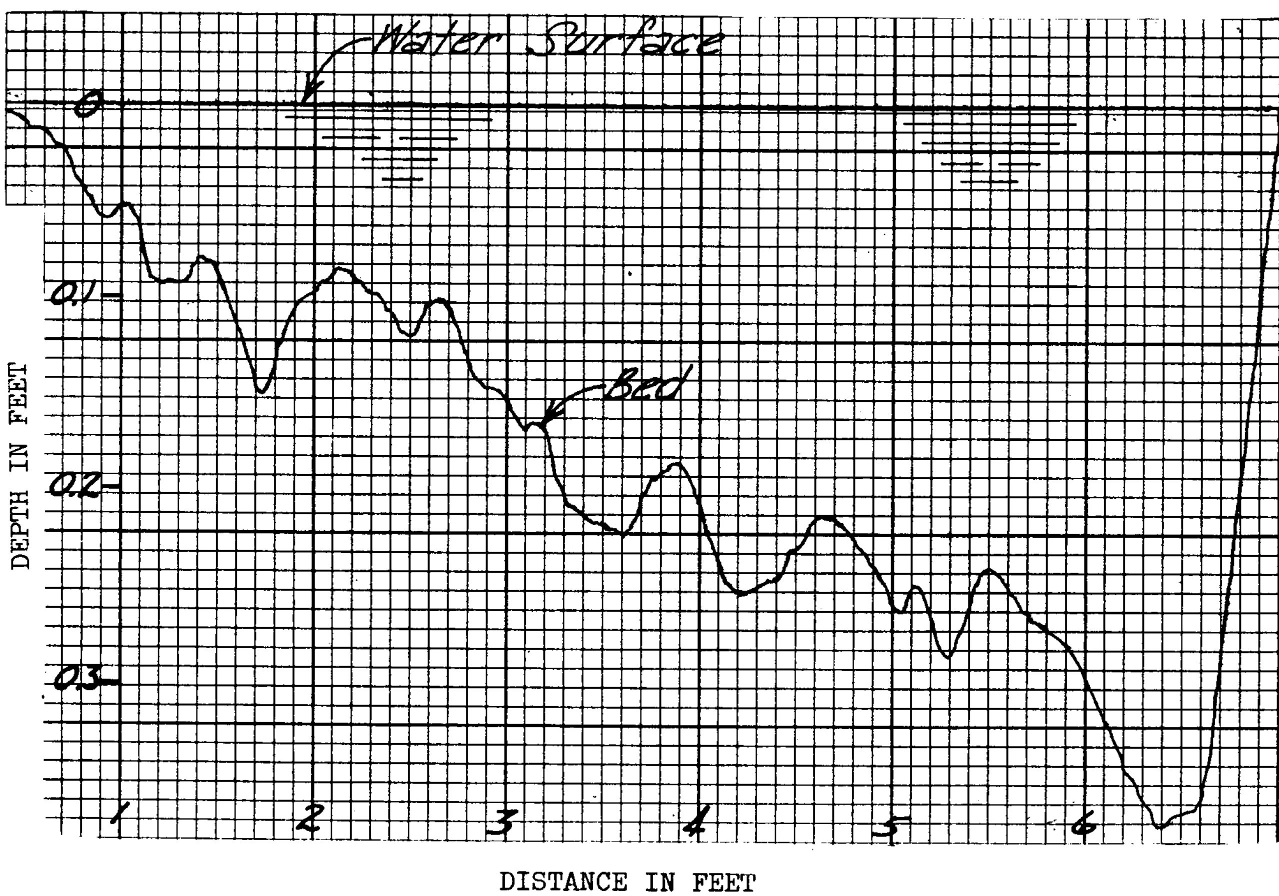





Figure 13

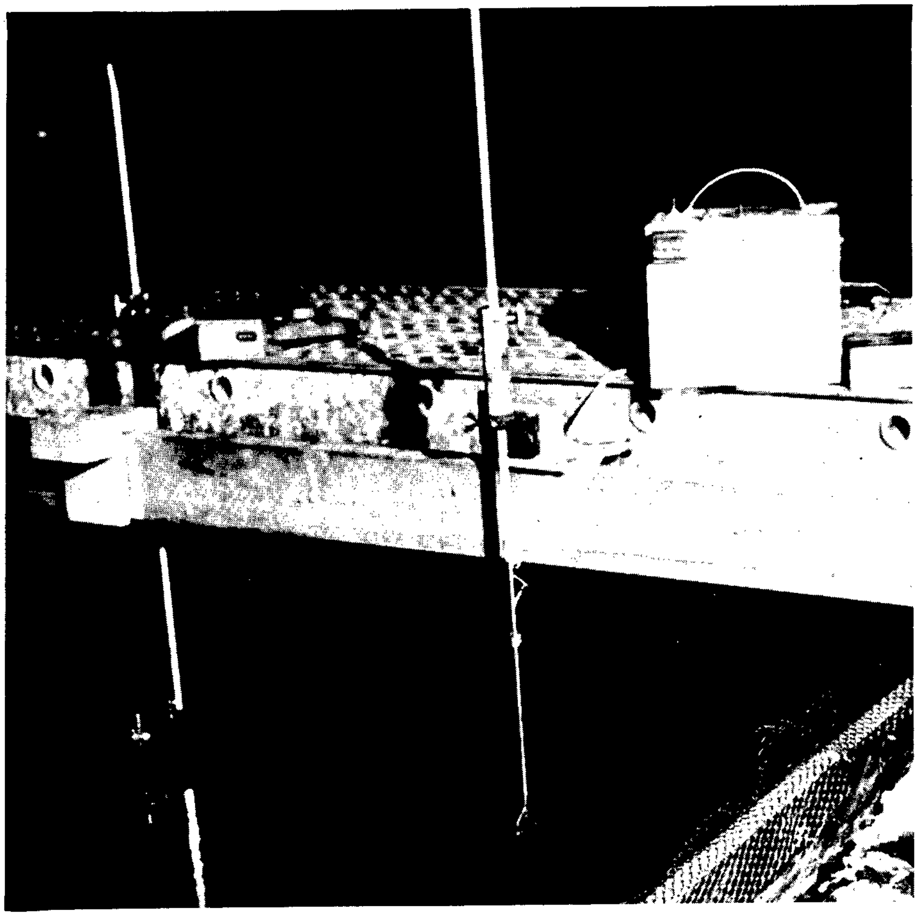


Figure 14. Velocity distribution data in the model is obtained with either a Pygmy current meter on the left or with a Stevens meter shown on the right. Revolutions are recorded by the attached counting mechanism.

## MODEL BED MATERIAL

27. The material normally used for the stream bed and channel banks at the Mead Laboratory are ground walnut shells. This lightweight material is available commercially at relatively low cost in various size gradations. The material selected for use at this laboratory has a specific gravity of about 1.30 and a median size of 0.30 mm.

28. The material has several operational advantages. Because of its relatively light weight, the length of time necessary for the model to reach an equilibrium condition is greatly reduced. The material can also be carried in suspension at rather low velocities, thus permitting one to simulate deposition resulting from suspended or bed sediment transport.

29. Ground walnut shells are similar to Missouri River sand in several important characteristics. By controlling the gradation, the particle size distribution for the two materials can be made almost identical, even though the specific gravity varies between the two materials.

30. Photomicrographs of the two materials illustrated in Figure 15 indicate the shape factors are similar. This is further verified in Figure 16 which shows the relationship between the drag coefficient and Reynolds Number for both Missouri River sand and ground walnut shells, which indicates that the two materials have similar settling characteristics.

Walnut Shells

Missouri River Sand

Figure 15. Photomicrograph of test materials, Grid Size: 0.39 mm.

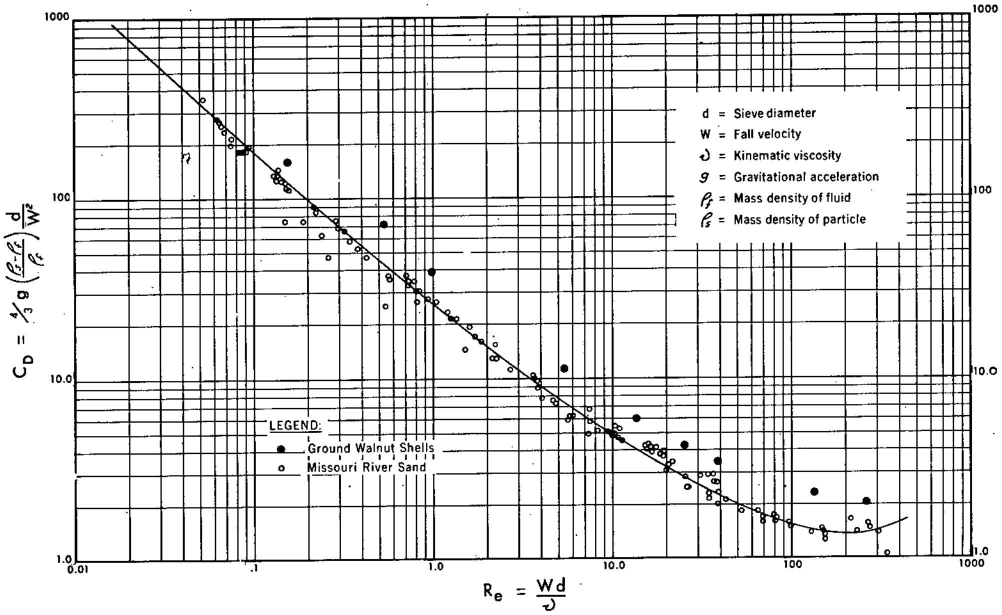



Figure 16. Drag coefficient vs. Reynolds Number for Missouri River sand and ground walnut shells.

Figure 17. The above photo shows the finely ground walnut shells used as the bed material in the model. The shells are available commercially in several convenient size gradations.

31. Tests at the laboratory have utilized both ground black walnut shells and ground English walnut shells. Physical characteristics such as particle size distribution and specific gravity are similar. The English walnut shells appear to be generally cleaner, freer of foreign material and less susceptible to bacteria growth. Bacteria growth in the model bed is a continual problem during warm weather periods and appears to be related to the length of time during which the material is submerged. A gas is generated which bubbles to the surface which sometimes creates a general swelling or lifting of the bed. The addition of copper sulphate to the flume and frequent mixing of the bed material appear to minimize the problem. The bacteria growth does not appear to cause any breakdown or deterioration of the walnut shell material.

32. The walnut shells have a tendency to discolor the water, particularly the first few times water is added to the system. This effect can be diminished by frequently changing the water in the system, but this does not completely eliminate the problem. The slight discoloration limits underwater visibility but does not effect the performance of the model in any manner. Black walnut shells appear to discolor the water slightly more than English walnut shells.

33. Costs of the material have varied between $80 and $160 per ton including transportation. The most recent purchase (1967) was for ten tons of English walnut shells and cost $98 per ton delivered from California to Omaha, Nebraska. The following companies are known sources of supply.

a. Agrashell, Inc.
640 North 13th Street
Easton, Pennsylvania 18042

b. C. P. Hall Company
5245 West 73rd Street
Chicago, Illinois 60638

c. Queen Products Company
Albert Lea, Minnesota 56007

d. Composition Materials Company, Inc.
25 West 43rd Street
New York, New York 10036

e. Hammons Products Company
217 Hammons Drive
Stockton, Missouri 65785

## TEST PROCEDURE

34. A typical model investigation is started by placing a system of river training structures at their desired test locations between the outer basin walls of the flume. These may be constructed of either concrete, wood or sheet metal. Many times it becomes necessary to artifically roughen the surfaces of these structures with either roofing material or with expanded sheet metal to insure the proper flow distribution adjacent to the structures. Figure 18 shows a typical layout before the walnut shells have been placed in the flume.

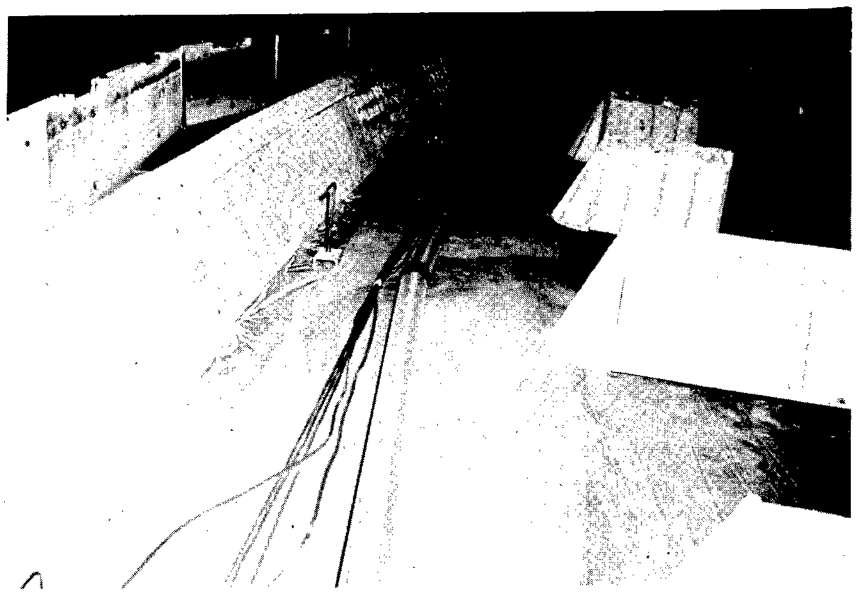
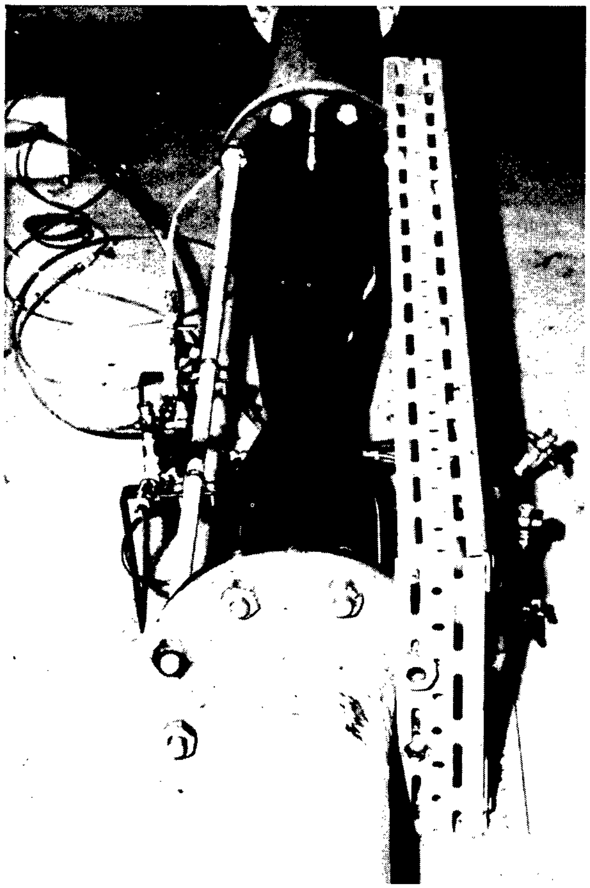
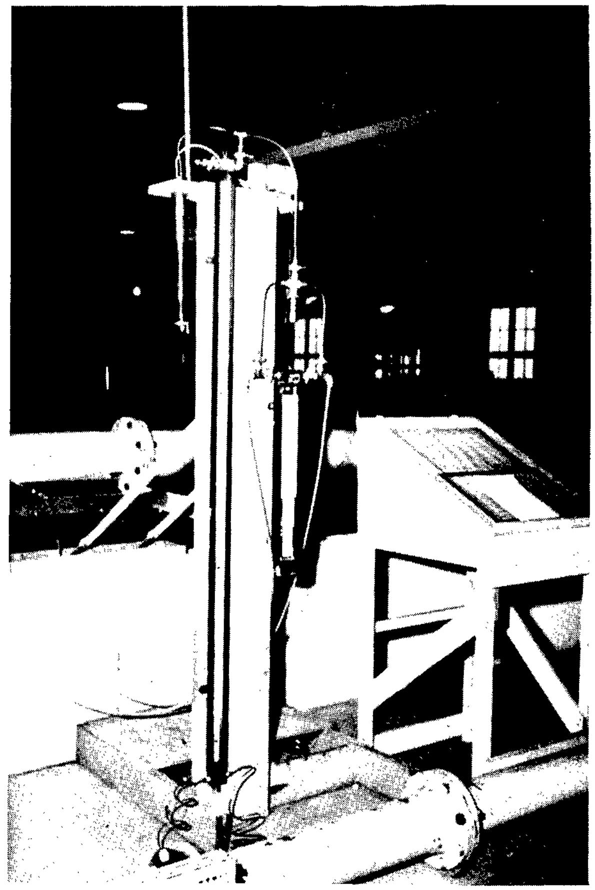


Figure 18. Typical model layout before installation of walnut shells.

35. The remaining basin area is then filled with ground walnut shells. The walnut shells are placed in and around the training structures and thus form the bed and banks of the model stream. The shells are generally pre-shaped into a trapezoidal section at the beginning of a test, and then allowed to form its final shape by the combined action of the water and the sediment.

36. The system is next filled with water and allowed to stand a sufficient length of time to insure that the bed and banks of the stream are completely saturated with water. The pumps are then started, and the discharge rate adjusted by controlling the speed of the motors. This rate is measured by observing the differential head across a venturi type meter installed in the pipe connecting the pumps to the entrance of the flume. The depth of flow in the model is adjusted as desired during a test run by either adding or draining water from the system. There is no tailgate or depth control structure used in the system, therefore the water surface and bed slopes are free to adjust themselves to fit a given set of model conditions.

The discharge is determined by measuring the differential pressure across the meter shown in Figure 19 on the left. This is then transferred to the differential manometer shown in Figure 20 on the right. The water columns in the manometer are held at a convenient level by means of a vacuum pump.

37. The water surface slope and total amount of material being transported through the system are continually monitored as a test is being made. Each of these parameters serve as indicators of what is happening in the flume and when the system is approaching an equilibrium condition. Considerable fluctuation can usually be noted in each of these functions in the early part of a testing period, but the fluctuations tend to diminish as the system stabilizes. Data of this nature also assists in correlating successive model tests.

38. The model usually begins to stabilize after a few hours of operation, and most tests have essentially stabilized after eight hours of continuous running time. Bars and dunes on the bed of the model continue to move through the system, even under an equilibrium condition, but no overall changes in the regions of scour or deposition occur. When this condition exists, the pumps are stopped and cross section data is collected. These are obtained with the sounding apparatus described in paragraph 23 of this report. Additional water is usually required in the system during the measuring operation to insure sufficient water depths over the individual bar formations. The entire flume is then drained slowly by means of small submersible sump pumps. The water leaves the flume by filtering down through the walnut shells and into a perforated drain pipe located in the bottom of the flume. This method of draining preserves the actual dune formations and allows a visual inspection of the bed at the completion of each test. Significant results and details of the test are then recorded for future reference. The results of a given set of training structures can generally be known in about 1½ days.

## MODEL VERIFICATION

39. The Pomeroy Bend model investigation[6] performed at the Mead Laboratory is an illustration of the verification procedure employed on a typical laboratory study. Prototype measurements indicated that the position of the thalweg and navigation channel was very unpredictable, sometimes being located against the outer portion of the bend, and other times toward the inside. Model reproduction of this instability was one of the most important prototype characteristics requiring verification.

40. Prototype measurements on this reach of the river were available for two separate stability regimens. The first was as the river existed prior to the installation of low underwater sills on the convex (inside) bank of the bend. When the river existed in this state, the channel was confined between a complete rock revetment on the concave bank, and short spur dikes projecting into the channel on the convex bank. The unobstructed width was 750 feet. Under these conditions, the prototype was in an unstable condition at the normal navigation discharge of 35,000 cfs. However, after the low sills were constructed on the inside of the bend, a more stable navigation channel resulted, and many of the large bars which were previously present no longer existed. These two conditions, both at the same discharge, served as an excellent test on the models reproduction ability.

41. To assist in the selection of a correct set of scales for this model, a series of preliminary tests were conducted in which the depth and velocity were varied and the width held constant. This permitted observation of the bed formations and the channel characteristics under a wide range of conditions. Figure 21 shows the results of these studies in graphical form for the Pomeroy Bend model.

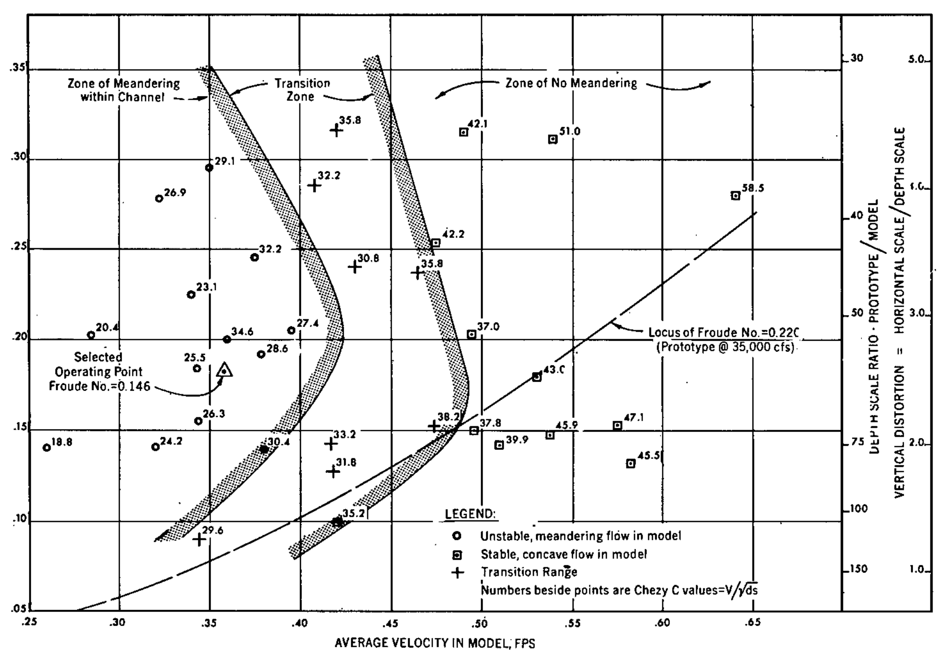



Figure 21. Velocities and depths for various channel stability regimes in the Pomeroy Bend Model.

42. The points on this graph are divided into three groups or classifications. One group consists of the tests in which the channel was definitely in an unstable state within the model boundary and no clear cut channel was evident in the bend. Those points are located toward the left portion of the plot. In contrast to these, a second group of points is labeled as concave flow. These points, located to the right on the plot, indicate tests in which the channel was well defined, with the major flow concentrated along the outer or concave side of the bend throughout the reach. In between these two regions, there are combinations of depth and velocity where the channel could not be clearly defined either as concave or meandering. Those are labeled as being in the transition range.

43. The solid line on the plot gives combinations of depth and velocity which satisfy the Froude criteria. It is important to note, that at only very shallow depths does one even approach Froude similarity. However, attempts to operate the model at these shallow depths is extremely difficult to evaluate and control. A set of operating conditions was selected from this graph which would satisfy the physical restraints of the system and still keep the distortion between the horizontal and vertical scales to a minimum. An average depth of flow in the model of 0.18 feet with a corresponding velocity of 0.36 fps was found a meet these criteria.

44. Since the channel was altered considerably by construction of the underwater sills, a second set of conditions for verification of the model was available. Using the scale relationships which satisfactorily reproduced the prototype prior to installation of the underwater sills, the model was reconstructed with the underwater sills. The model was then placed in operation, and the scales adjusted until a combination was found which would reproduce the prototype under both known conditions. This does not mean that each dune and scour hole was literally reproduced in the model, but that the model was in the same state or condition as the prototype. It is recognized that this method of verification must be carried out for each basic discharge to be studied, providing adequate field data are available, as the model scale in some cases could change for alternate discharges.

45. The Manawa-Bellevue reach is an illustration of a totally different problem in the Missouri River. In this reach the flow was highly concentrated along the outside of the bend, resulting in a very narrow deep channel, with high velocities. Therefore, the verification procedure in this study required the proper reproduction of the lateral distribution of the flow. Once again, the depth and velocity were allowed to vary until the proper flow distribution had been established. In this model it was not possible to get complete reproduction of prototype conditions without using artificial roughness along the concave

bank. The plot on Figure 22 indicates the flow distribution of tests prior to and after the installation of this roughness and the results are clearly evident. Comparisons such as these were made at several key locations in the testing region.

46. One indication that the model reacts as an alluvial river and that generalization from the model results may be valid is illustrated in Figure 23 which presents a relationship for river channel roughness suggested by Einstein and Barbarossa. Data from the Pomery Bend, and Manawa-Bellevue models seem to fit the same dimensionless relationship as data from reaches on the Mississippi and Missouri Rivers, although the bed material used in the models was ground walnut shells. It will be noted that the data points from measurements made in a straight-walled flume at the University of Nebraska turn to the right at a $\psi'$ value of about 10. This tendency for data from straight-walled flumes to deviate from the trend for natural rivers has also been observed by Simons and Richardson.[8] It is possible that an alluvial channel model that avoids the non-similarity to natural rivers imposed by straight side walls in laboratory flumes will prove to be a useful tool for studying the hydraulic resistance and sedimentation characteristics of rivers.

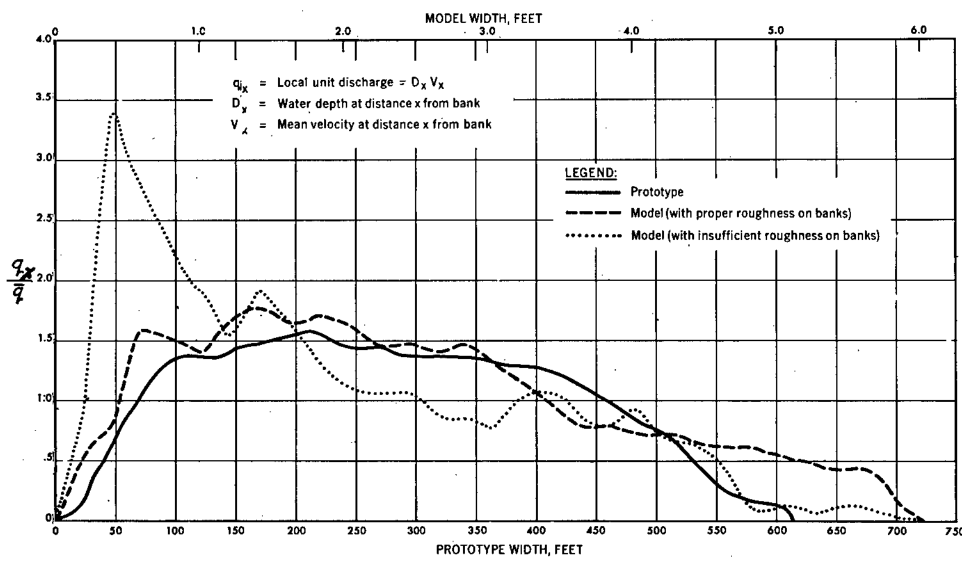



Figure 22. Lateral flow distribution in crossing of Manawa-Bellevue Reach of the Missouri River.

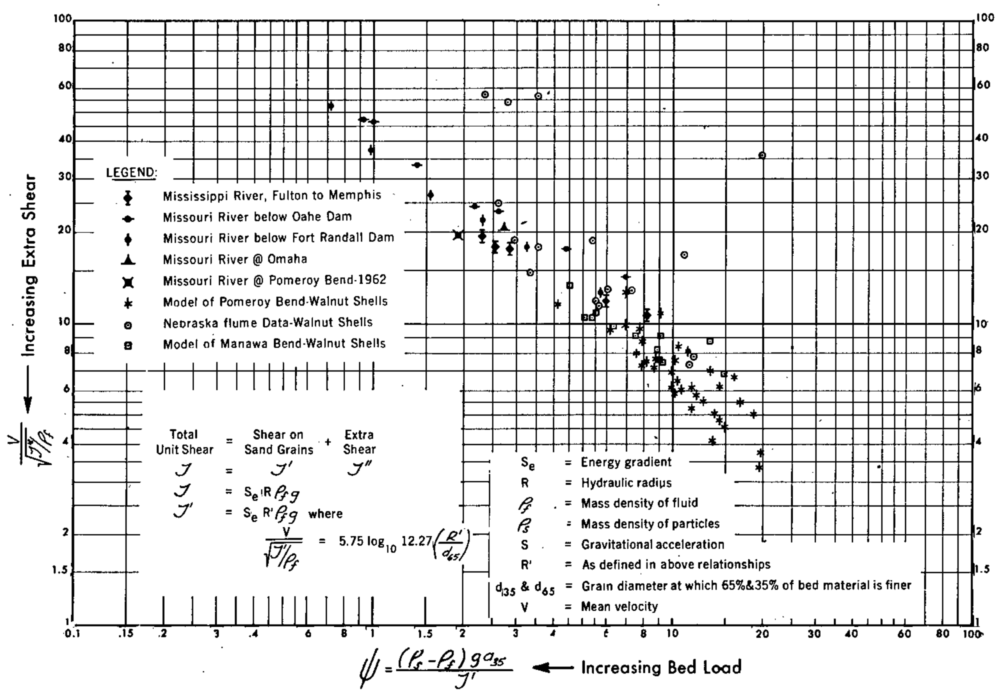



Figure 23. Roughness characteristics of several rivers and models.

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